Robots and societal relations

Václav Hlaváč

Czech Technical University in Prague

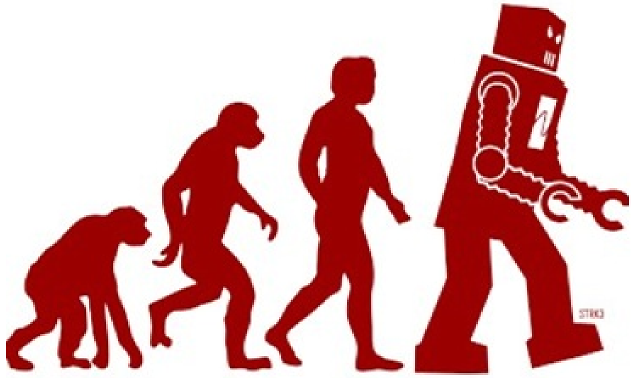
Czech Institute of Informatics, Cybernetics and Robotics (CIIRC)

160 00 Prague 6, Jugoslávských partyzánů 1580/3, Czech Republic

vaclav.hlavac@cvut.cz, http://people.ciirc.cvut.cz/hlavac/

Four societal issues addressed in this lecture

1. Automation, including robotics as a source of a labor productivity increase.
2. Influence of automation/robotics to society wealth and its distribution among the population.
3. Autonomous robotics as one practical outcome of artificial intelligence sharing its theoretical limits.
4. Robotics as a game changer in labor safety in a factory shop floor and elsewhere.



Why are we interested in (autonomous) robots?

Our robot definition:

A physically-embodied, artificially intelligent autonomous device, which can sense its environment and can act in it to achieve some goals.

Why are we interested?

- We like to compare our abilities with the nature (symbolically). We intend to check how far do our creative abilities span and by means of repetition to penetrate into Laws of Nature.
- We intend to produce a perfect helper with abilities comparable to ours and who might be even more reliable than humans.

Two taxonomies often used in robotics

Principal behaviors and needed effectors

- Locomotion: Moving around, going to places.
  - Still base (e.g. an industrial manipulator), wheeled, tracked (e.g. a tank) – are the most common.
  - Legs. Statically stable – can pause at any stage. Dynamically stable – stable as long as it keeps moving.
  - Other: fish-like, snake-like, etc.
- Manipulation: handling objects.

Application areas examples

- Manipulator robotics
- Mobile robotics
- Communication robotics, e.g. museum guide, toys

Various approaches to robotics

- **Theoretical robotics:** searches for principles, potentials and constraints (biology, psychology, etology, mathematics, physics).
- **Experimental robotics:** checks principles, builds toy devices (cybernetics, artificial intelligence, combination of engineering disciplines).
- **Experimental (industrial) robotics:** Designs, builds and uses robots (control engineering theory and instrumentation, electronics, machine engineering, production automation).
- **Miscellaneous applied robotics:** Designs various intelligent machines for industry and elsewhere. For instance, machines for quality check in production are often endowed by the ability to see, mobile robots are able to navigate autonomously, etc.

Industrial revolutions

1st industrial revolution	$\sim$ 1800	human labor replaced by mechanical one, driven by water wheel, steam engine
2nd industrial revolution	$\sim$ 1900	production electrification, mass production
3rd industrial revolution	$\sim$ 1960	elecronization, robotization of production, software-based control systems
4th industrial revolution	now	cyberphysical systems, everything is connected to internet

A German government initiative Industry 4.0; The first use of a concept in 2011; It promotes the computerization of manufacturing. It is based the technological concepts of cyber-physical systems, the internet of things.

Production and its automation

Proliferation of mechanization, automation and robots =>

- decrease of the human presence in production,
- shortening the production time (namely auxiliary one),
- increase of performance and productivity of labor.

Notes

- Technical, economic and social viewpoints.
- Automation decreases the influence of the human factor to the quality of production.
- The qualification structure of the work force is changed.
- The number of workers decreases which influences the unemployment.

Concepts related to industrial robotics

- Mechanization, automation.
- Machines with partial automation, semiautomatic machines, automata.
- Numerically controlled (NC) machines.
- Automatic production line, automatized work cell, automatized workshop.
- Technological process is a collection of technological operations that leads from a semi-finished article to a product.
- Technologic operation, technologic position.
- Operational cycle
  - *periodic*: clock rate, cf. synchronous automaton.
  - *flexible*: flexible changes according to conditions, cf. asynchronous automaton.

Mechanization, automation

Illustration by two trivial examples from agriculture.

Cow stable mechanization – manure carrier.

Automatic cattle drinking water feeder.

Towards flexibility in automation

- **Substantial sources of the labor productivity increase**:
  - 1860 Replaceable parts, standardization.
  - 1913 Conveyer belt (Henry Ford)
    Machines in a fixed positions. Disadvantage: the failure of one machine stops the whole line.
  - 1994 Interchangeable production lines
    Universal machines and flexible transport of articles.
- **Structured/unstructured production**:
  - Structured ≈ effectiveness.
  - Unstructured ≈ flexibility.

1913 Flywheel magnetos

Charlie Chaplin, movie Modern Times 1936

Amount of produced articles and robots

- Production types according to number of produced articles

Production	Automation
Single piece	Flexible automation means
Small series	
Mass	Hard automation

- To which production type is the industrial robot usually deployed?
- Why?

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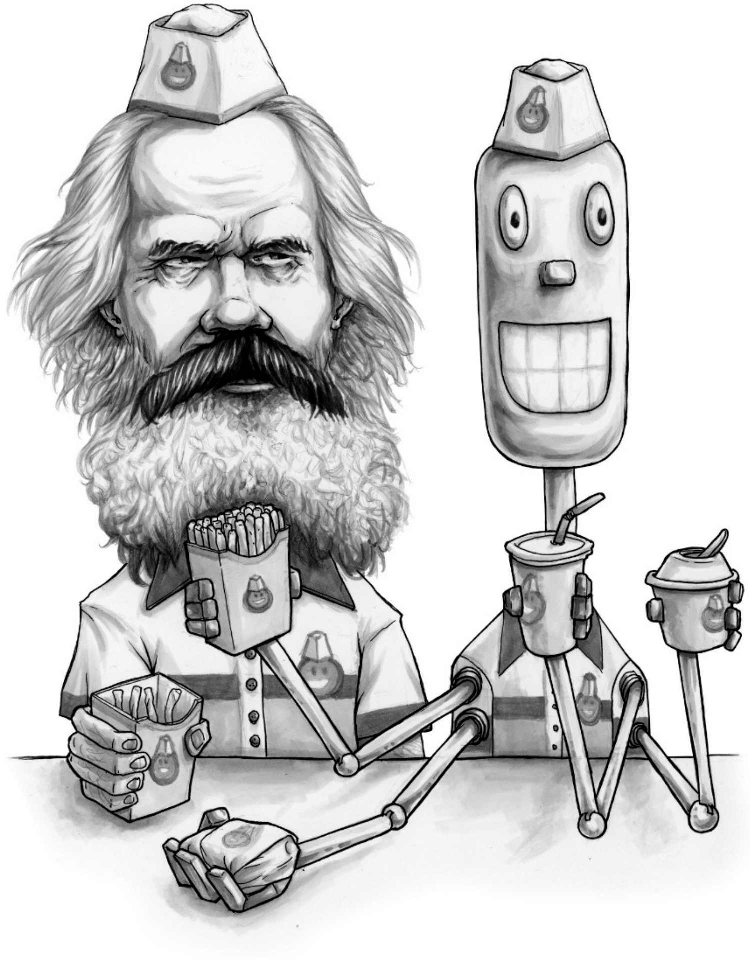
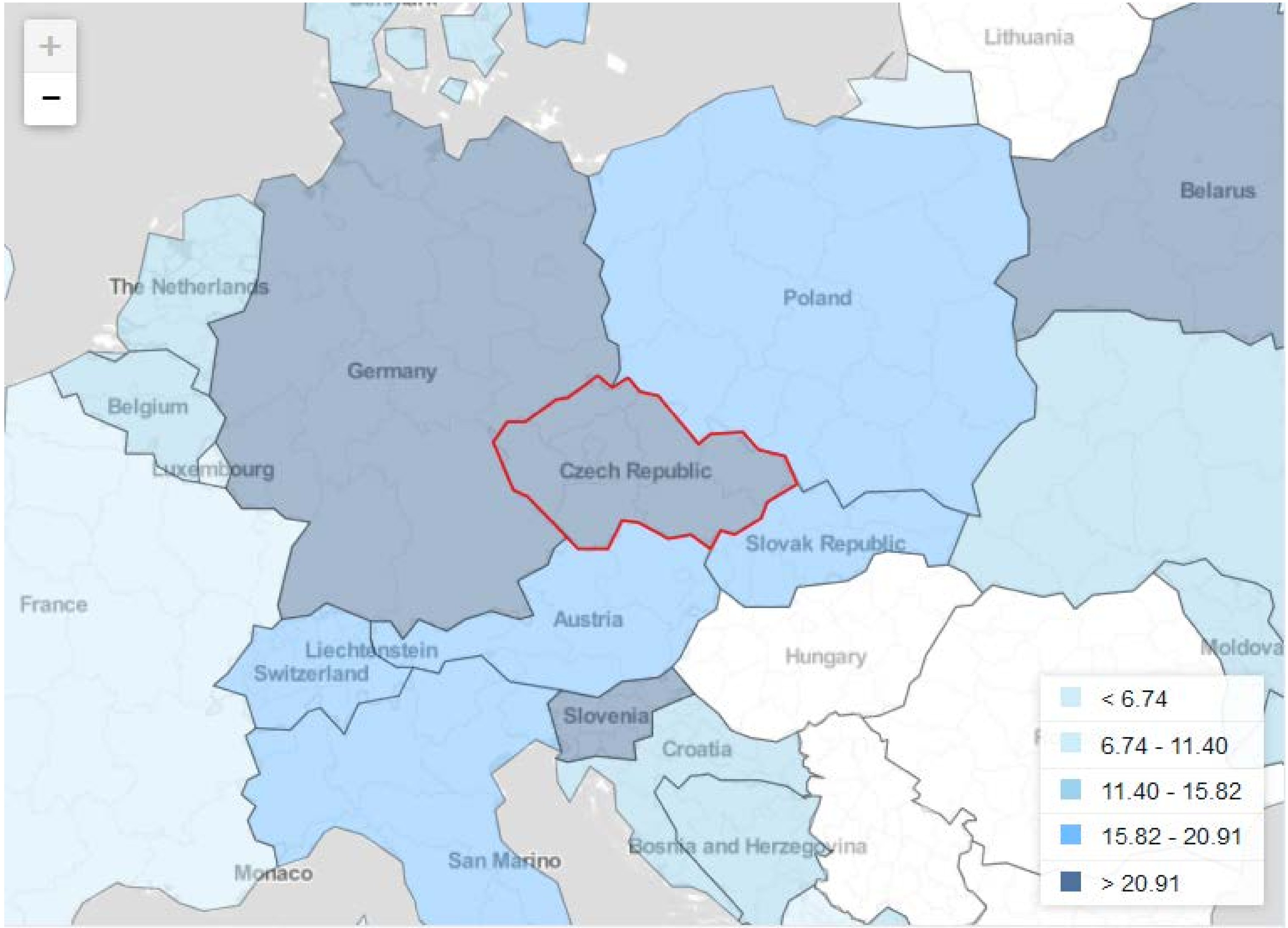
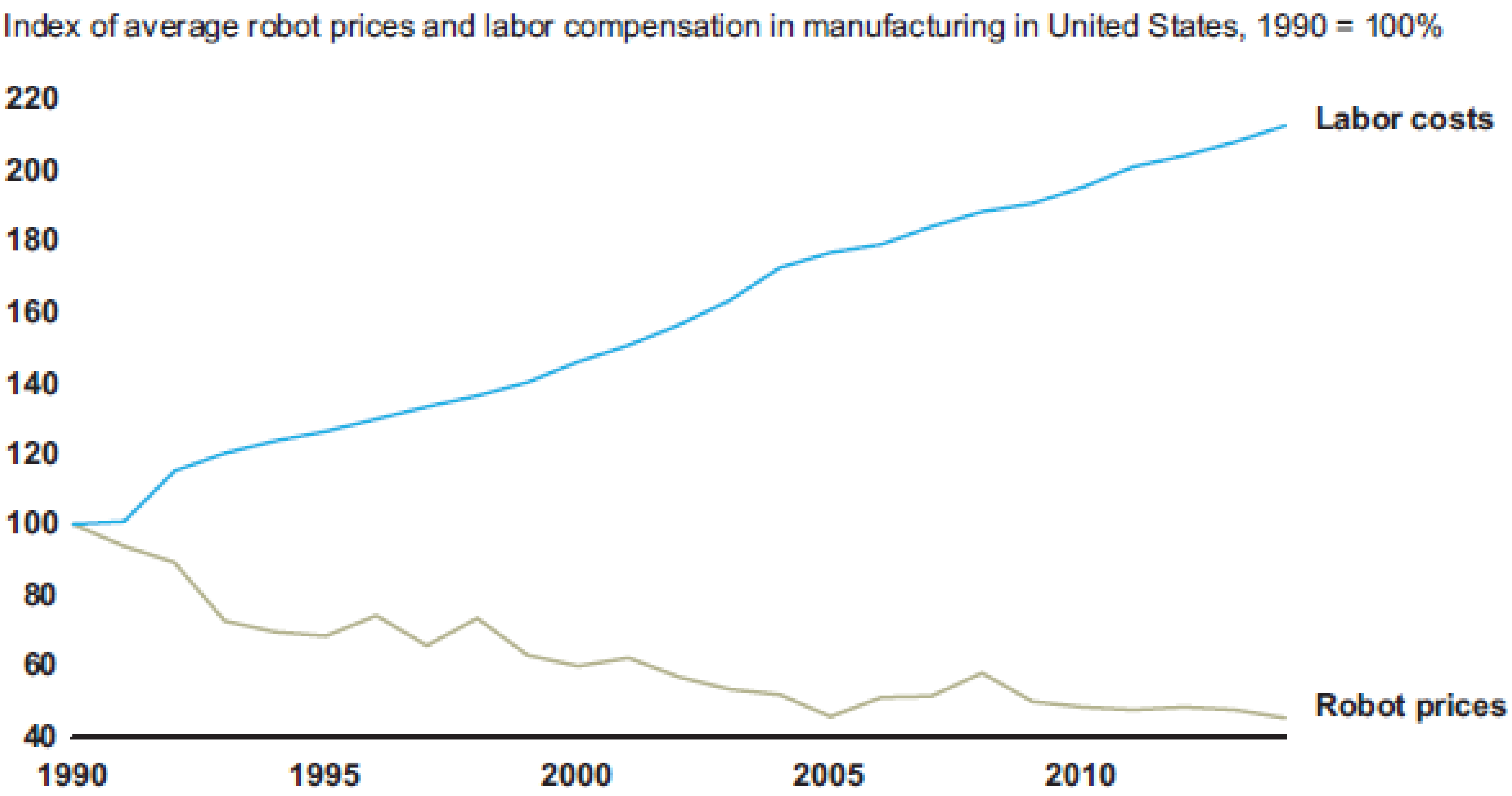


What would Karl Marx do?

Manufacturing, value added in % of GDP in Europe



Cost of automation



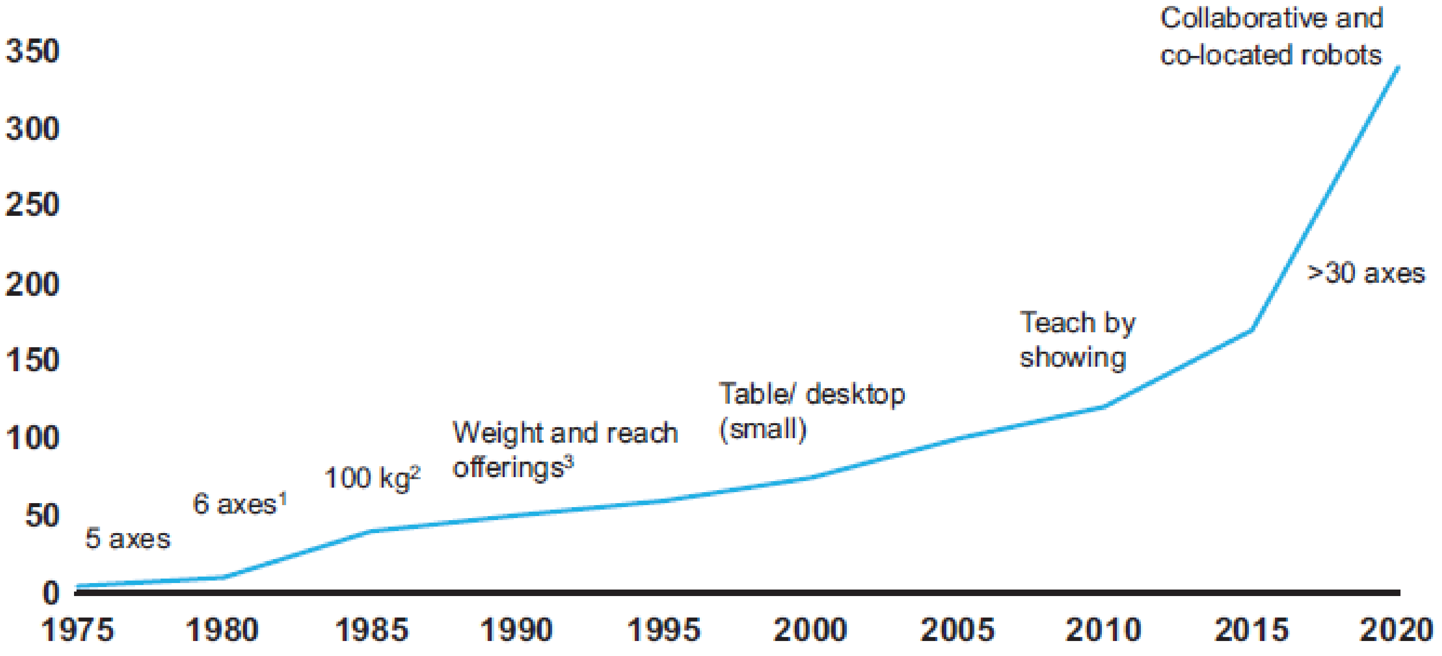
Source: J. Tilley, Automation, robotics, and the factory of the future, McKinsey 2017

Capabilities of robots have driven market growth

Growth of robots on the market

Base quantity SKUs

ILLUSTRATIVE



	1975	1980	1985	1990	1995	2000	2005	2010	2015	2020
Number of axes	5	6 to 8	12		21	27			32	
Kg capacity	6	60	90	>120				1,000		
Maximum reach (meters)	1		2					3		

1 Allows arc welding, adhesives dispensing, machine loading. 2 Spot welding, materials handling. 3 All application areas; right size for the task.

Source: McKinsey analysis

Source: J. Tilley, Automation, robotics, and the factory of the future, McKinsey 2017

2018 World bank & OECD data

- Manufacturing, value added (% of GDP)

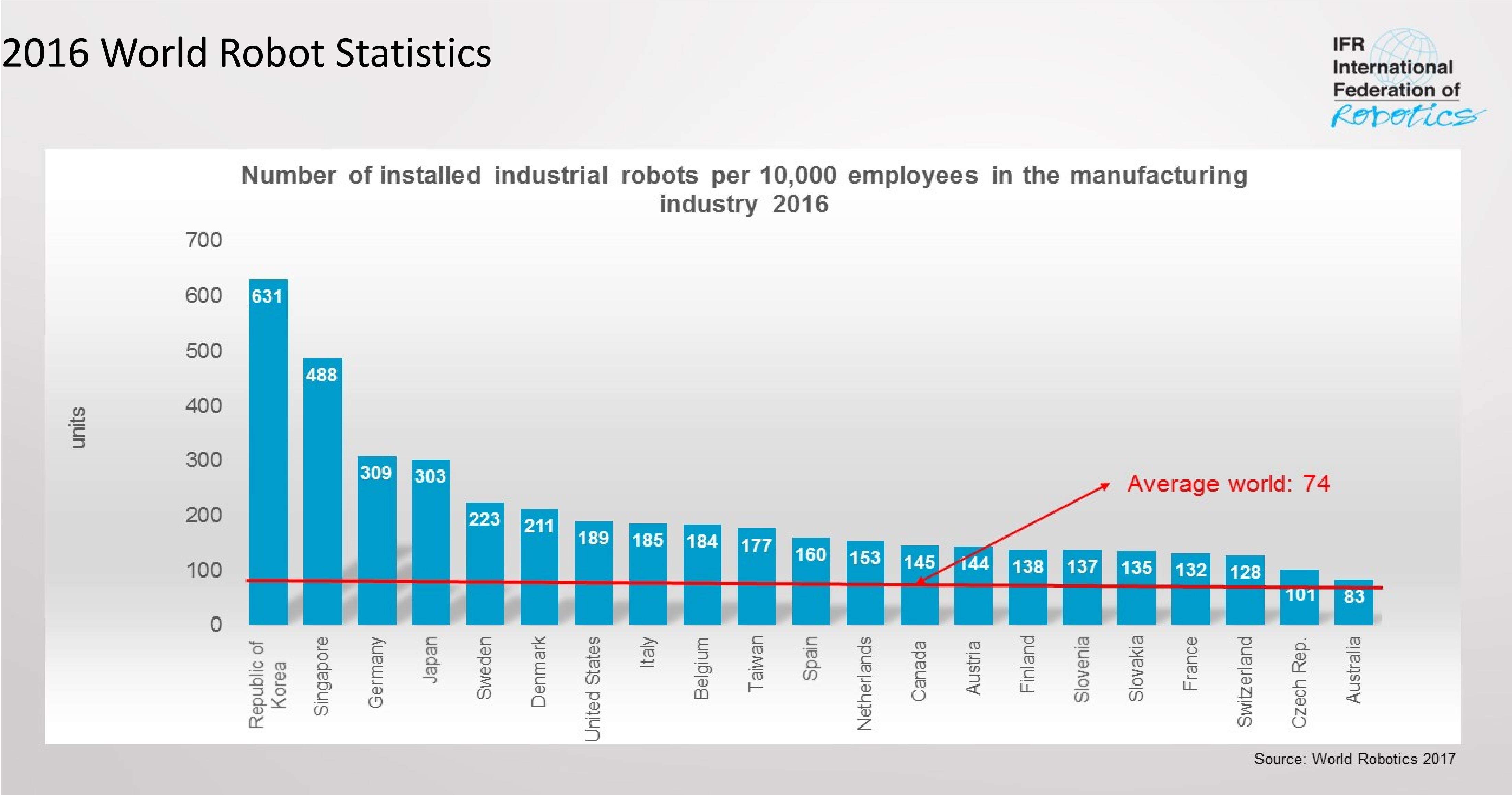
USA	Israel	Italy	Germany, Slovakia, Slovenia	Japan	Czech Republic	South Korea	China
11%	12%	15%	20%	21%	23%	27 %	29%

- Global manufacturing output
  - 55% China, Germany, Japan, USA (combined)
  - 45% The rest of the world

- Manufacturing sector contributing to Global Domestic Product
  - 1970: 25%
  - 2015: 15%

Number of robots per 10,000 workers

2016 World Robot Statistics



Economic comparison, data 2019

Country	GDP/capita USD	Employment by sector Agri/Industry/Services	Added value by % GDP Agri/Industry/Services
Ukraine	3,133	14.5 / 25.7 / 59.8	10.2 / 24.0 / 50.3
Russia	11,461	6.6 / 26.8 / 66.4	4.0 / 30.0 / 56.2
Czech Republic	24,938	2.8 / 37.4 / 59.3	2.2/ 33.5 / 54.2
Germany	49,692	1.3 / 27.6 / 61.9	0.6/ 27.6 / 54.2
USA	65,062	1.6 / 18.9 / 79.4	1.0 / 18.8 / 77.0

Source: https://www.nordeatrade.com/en/explore-new-market/

Manufacturing as a driving force of digital economy

- Convergence of communication, computing and automation. Best prepared: industrial manufacturing.
- Virtualization: IoT, the physical manufacturing is interlinked with the virtual world (digital representation), communication, and services (IoS); virtual twins.
- New Technologies as additive printing, clouds, methods of cybernetics, artificial intelligence and machine learning, machine perception, agent technologies.
- New Business Models: based on a high degree of autonomy of individual manufacturing units and connections to their "surroundings".
- Quite complex manufacturing systems do appear – these can be managed and controlled as distributed systems (community of agents).

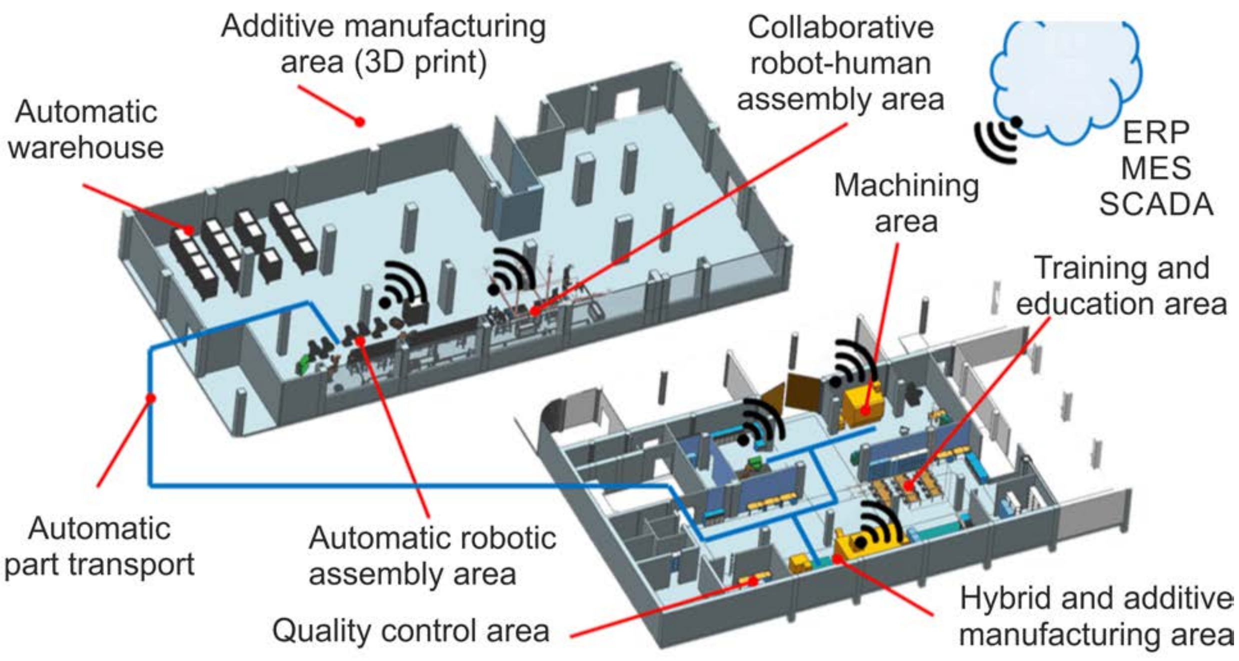
Vision: Inspire & Make the Czech Industry 4.0

- Implementation of Industry 4.0 principles, mainly in SMEs
- Increase awareness about Industry 4.0 and Society 4.0 (includes Center of City of Future and Center of Energy 4.0 at CIIRC)
- Cooperation between academia and industry
- Promote education and interdisciplinary research in Industry 4.0
- New R&D strategies and provide statements on Industry 4.0 topics
- Integration into the European infrastructure
- Establish a testbed network at CTU, Brno University of Technology, Technical University of Ostrava, and other institutions
- Promote know-how transfer to industry, including start-ups and managed innovations
- etc.

Testbed for Industry 4.0 at CIIRC CTU

- The very first testbed for Industry 4.0 in the country (Key support by the Czech and multinational companies)
- Opened on September 4th, 2017

- Particular goals:
  - Industry 4.0 compatible solutions for SMEs
  - Interoperability of Czech-made machine tools and SW solutions with Industry 4.0 facilities and standards
  - Creating community of companies, direct contacts of
    SMEs with global players



Testbed and its connection to Germany

- The Testbed is **linked with the testbed at DFKI Saarburecken** (the agreement signed during the visit of the Chancellor **Angela Merkel** to CIIRC in August 25, 2016)
- The German government dedicated **1 mil. EUR to buy collaborative robots** for DFKI to share them with CIIRC –the **virtual reality technology** will be used – **MRK 4.0 Lab**
- The testbed at TU Brno will be linked as well – we are jointly preparing a **large EU project RICAIP (15 mil. EUR) to virtually integrate testbeds** at CIIRC, DFKI and TU Brno

Testbed implemented architecture

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

User requirements

Connectors to other tools

Business Intelligence (**ABRA, SAP, …)**

Production control (**Siemens Simatic IT, SAP,** …)

Siemens Teamcenter PLM

Digital twin of the product – **Siemens NX, Simcenter**

Digital twin of the production process and equipment – **NX MCD, Tecnomatix**

Design CAD

Simulation & Co-simulation

Production planning & setup

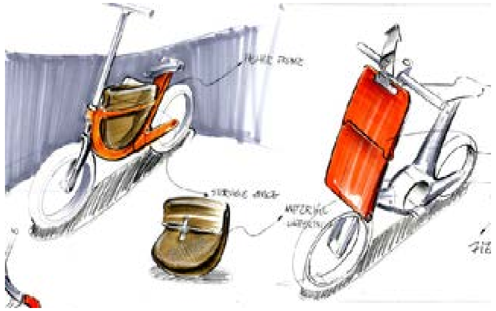
Supplier inputs

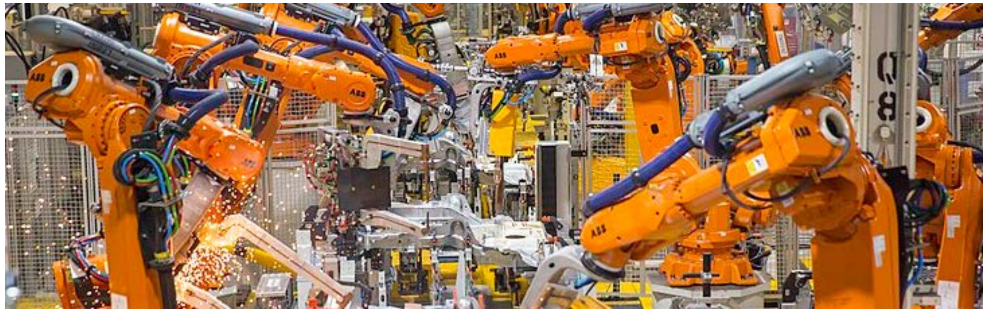
Quality management

Diagnostics & Maintenance

Design site

Production site





Azure

MindSphere

Leonardo

Product data

Process data

Data analytics

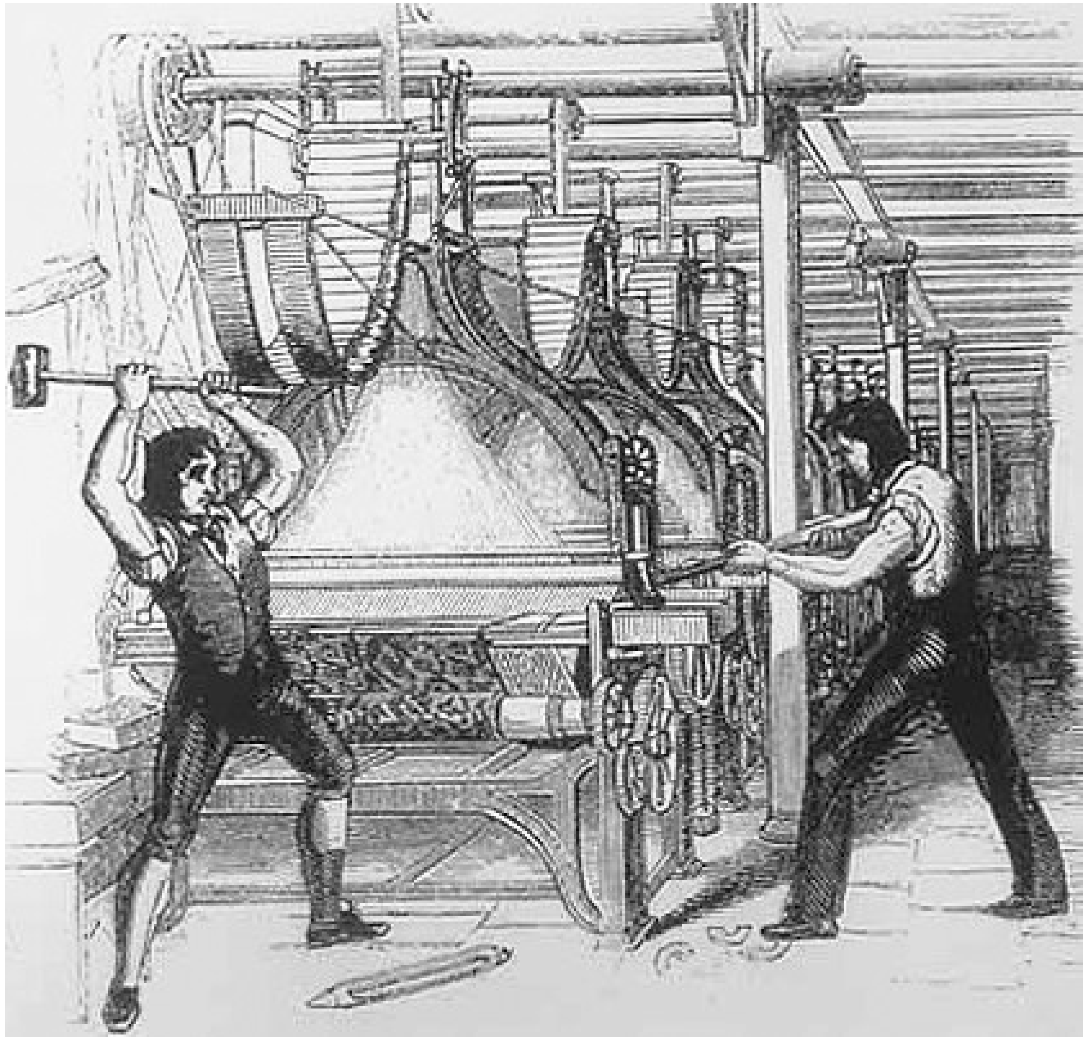
Productivity

- Productity is measured by the output for a unit input.
- Units can be
  - Work hours, i.e. human labor.
  - Total production cost = human labor + machines + energy.
- Two phenomena in productivity growth
  1. Growth phenomenon – e.g. the entire economy in improving through investment into new technologies and human force qualification.
  2. Shift phenomenon – e.g. low-income peasants move to cities and work in the hi-tech industry.

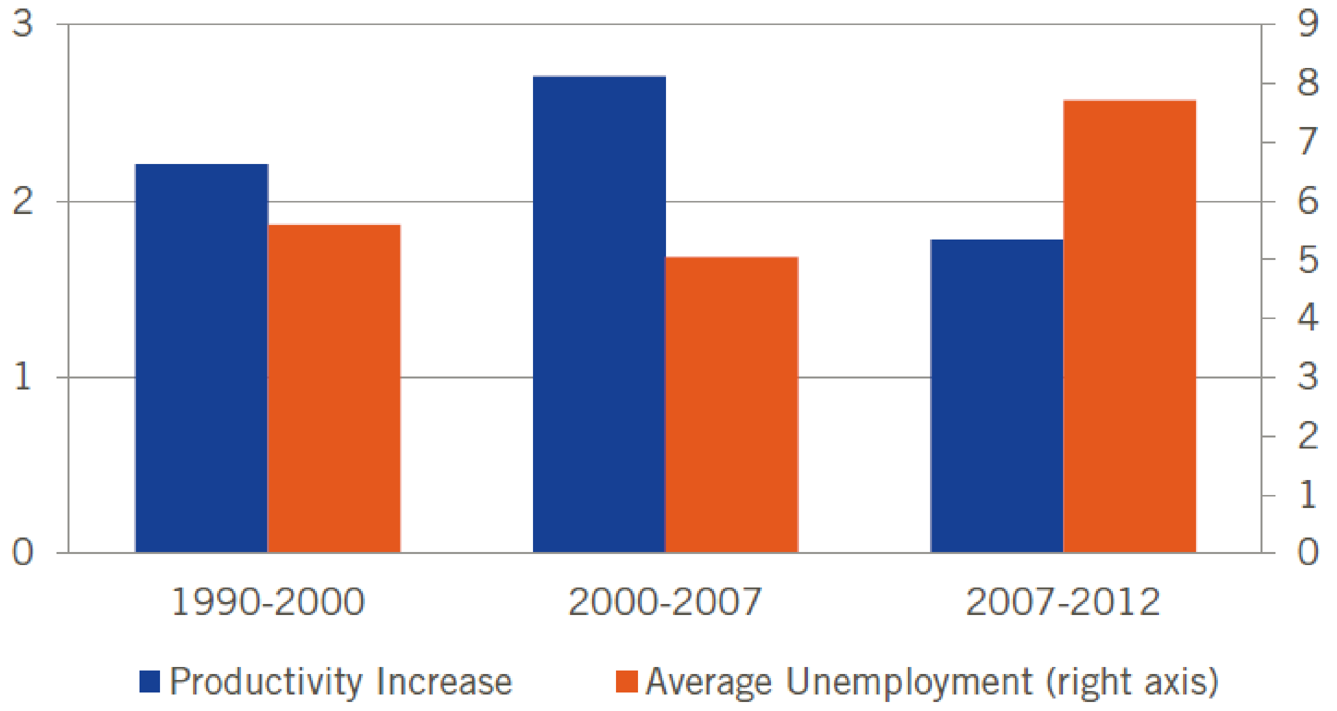
Fear of new technologies

- Luddits
  England 1812,
  Bohemia 1844
- Neoluddits:
  „Robot take our work “.

  Statistical evidence contradicts this fear. Example: Only 2.9% of workforce is employed in agriculture.



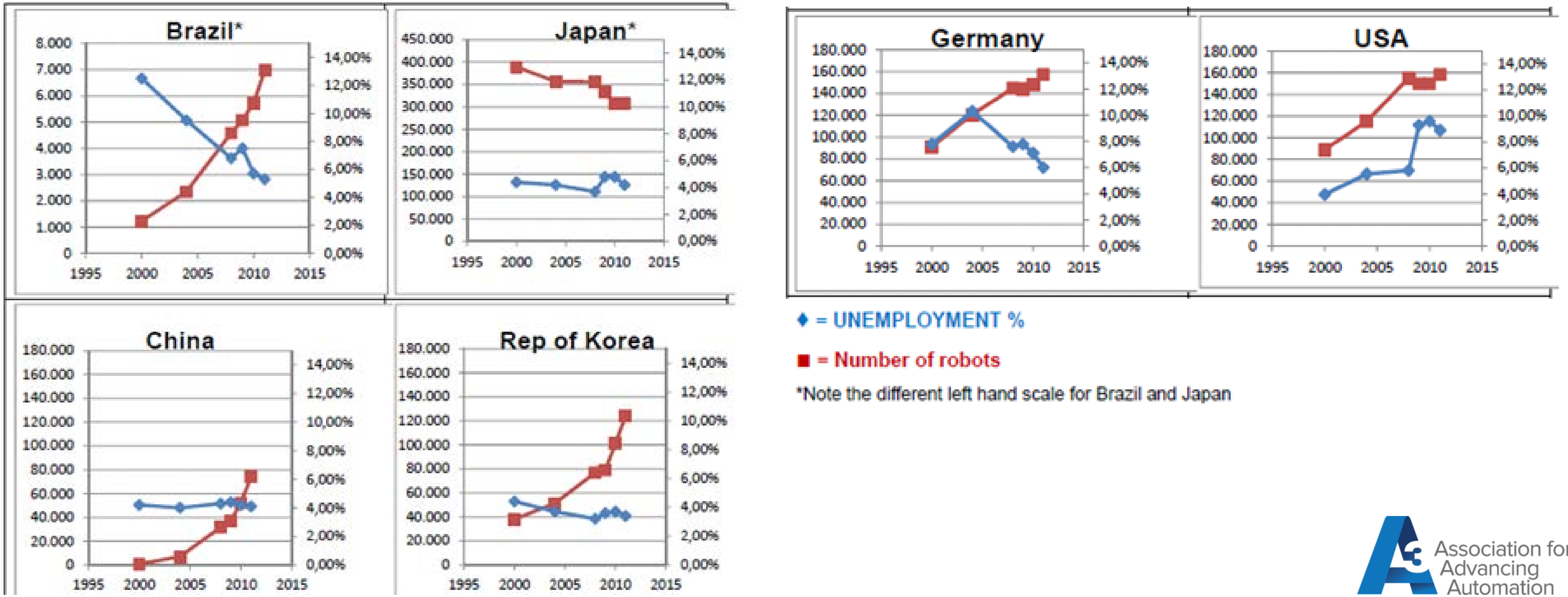
Productivity, employment in USA



Past development contradicts fears of neoluddits.

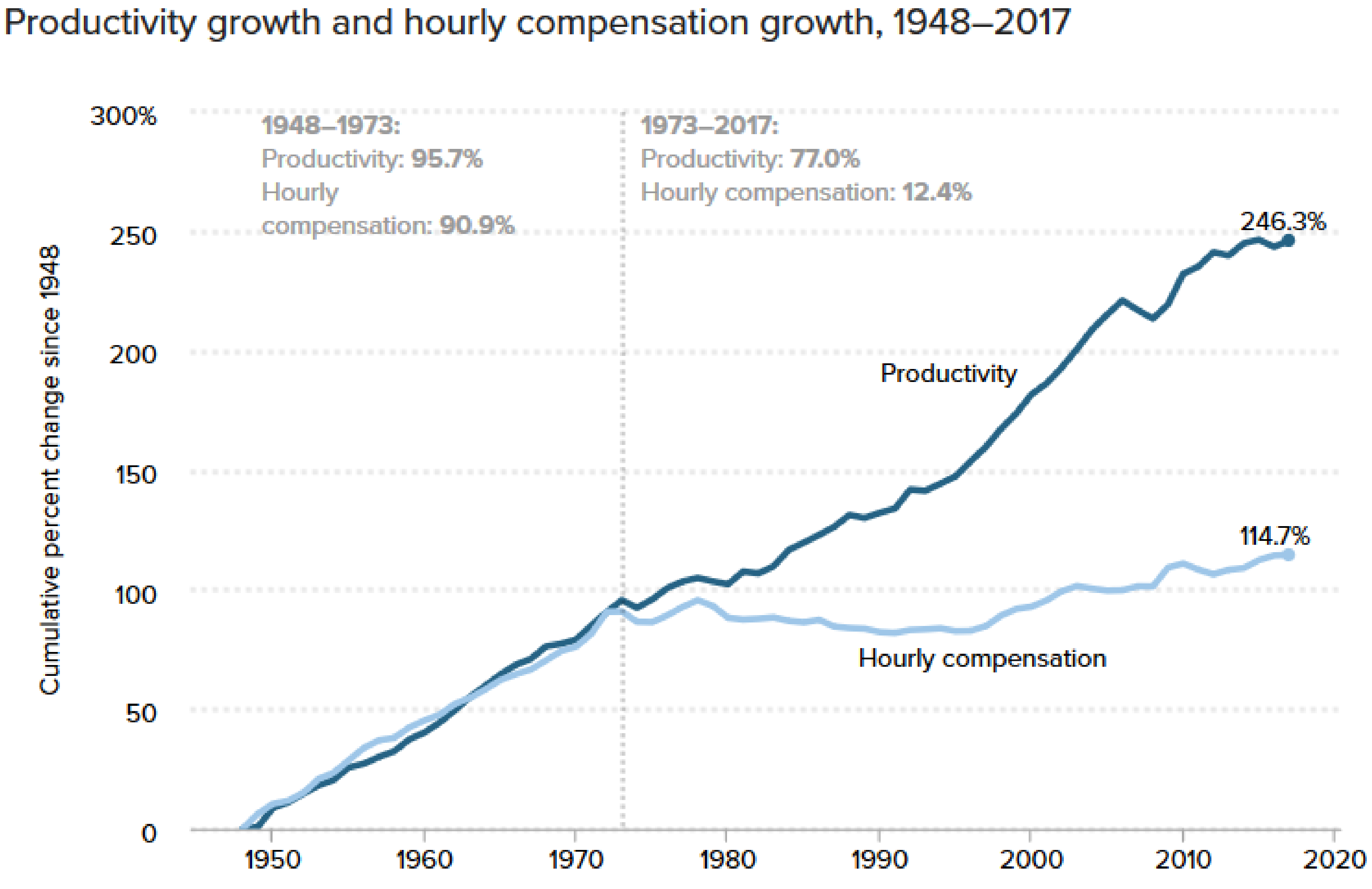
More robots decrease unemployment

Rate of unemployment trend vs Numbers of robots in use.



Association for Advancing Automation

The productivity – pay gap



Change 1973–2017:

- Productivity +77.0%
- Hourly pay +12.4%

Productivity has grown 6.2x more than pay.

Source:
Economic Policy Institute
March 2018

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Autonomous robot

- A qualitative change as compared to previous state.
- A robot decides on its own.
- The current top state in applications: robots with partial autonomy.
- Unclear consequences of theoretical limits, mainly Kurt Gödel's incompleteness theorems.
  Simply said: There are no consistent axioms which can be created by an algorithm proving rules of natural numbers arithmetic.
- Are you scared of superintelligence? Read the book Nick Bostrom: Superintelligence: Path, Dangers, Strategies, Oxford Press 2014

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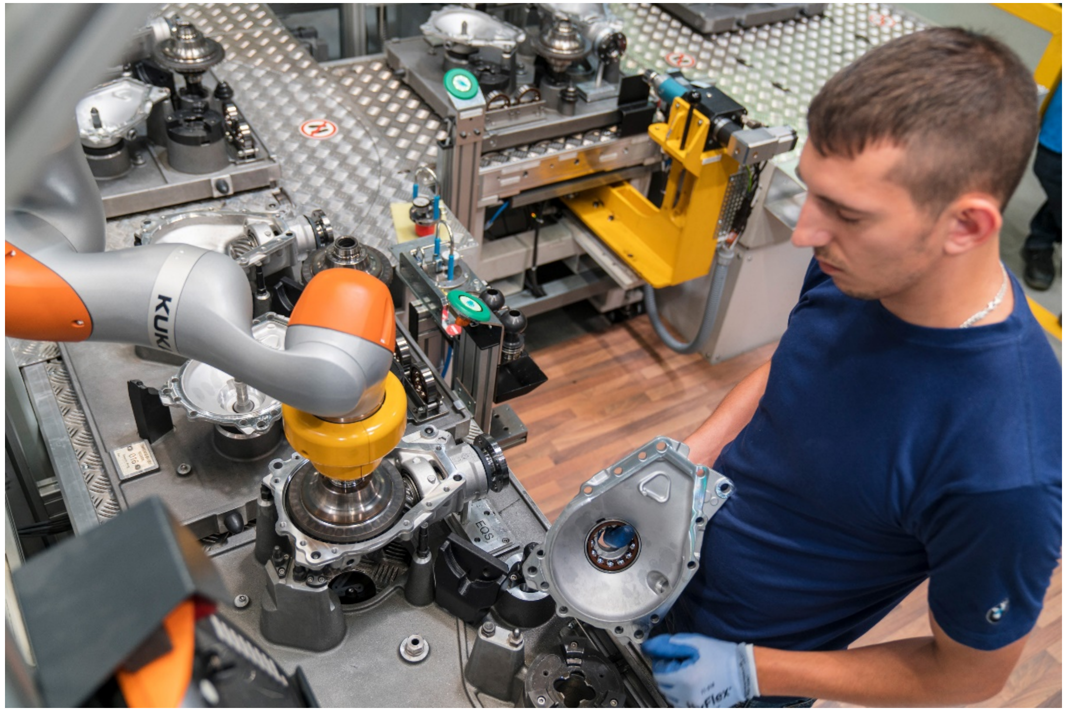


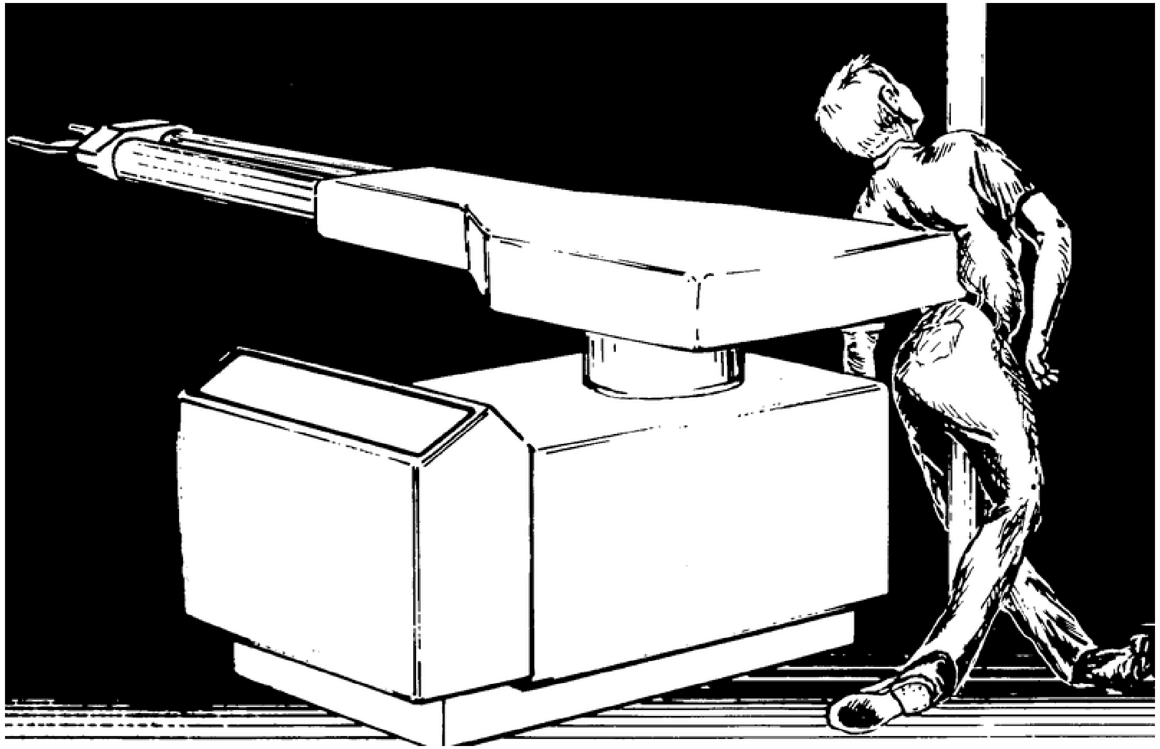
Safety - law vs. standards / norms

Law / directives

- are obligatory.
- EU gives directives.

Standards / norms

- are recommendations.
- Harmonized EU norms serve often as a base for EU directives



An artistic visualization of an 1984 incident.

State authorities overseeing safety

USA

- Occupational Safety and Health Administration - OSHA
- Mission:
  to ensure safe and healthful working conditions for working men and women by setting and enforcing standards and by providing training, outreach, education and assistance.

Czech Republic

- Státní úřad inspekce práce (State labor inspection office in Opava – SÚIP

Current Robot Safety Standards

- ISO 10218 Part 1 & Part 2 (2011)
- ANSI/RIA R15.06 2012 American National Standard for Industrial Robots and Robot Systems- Safety Requirements

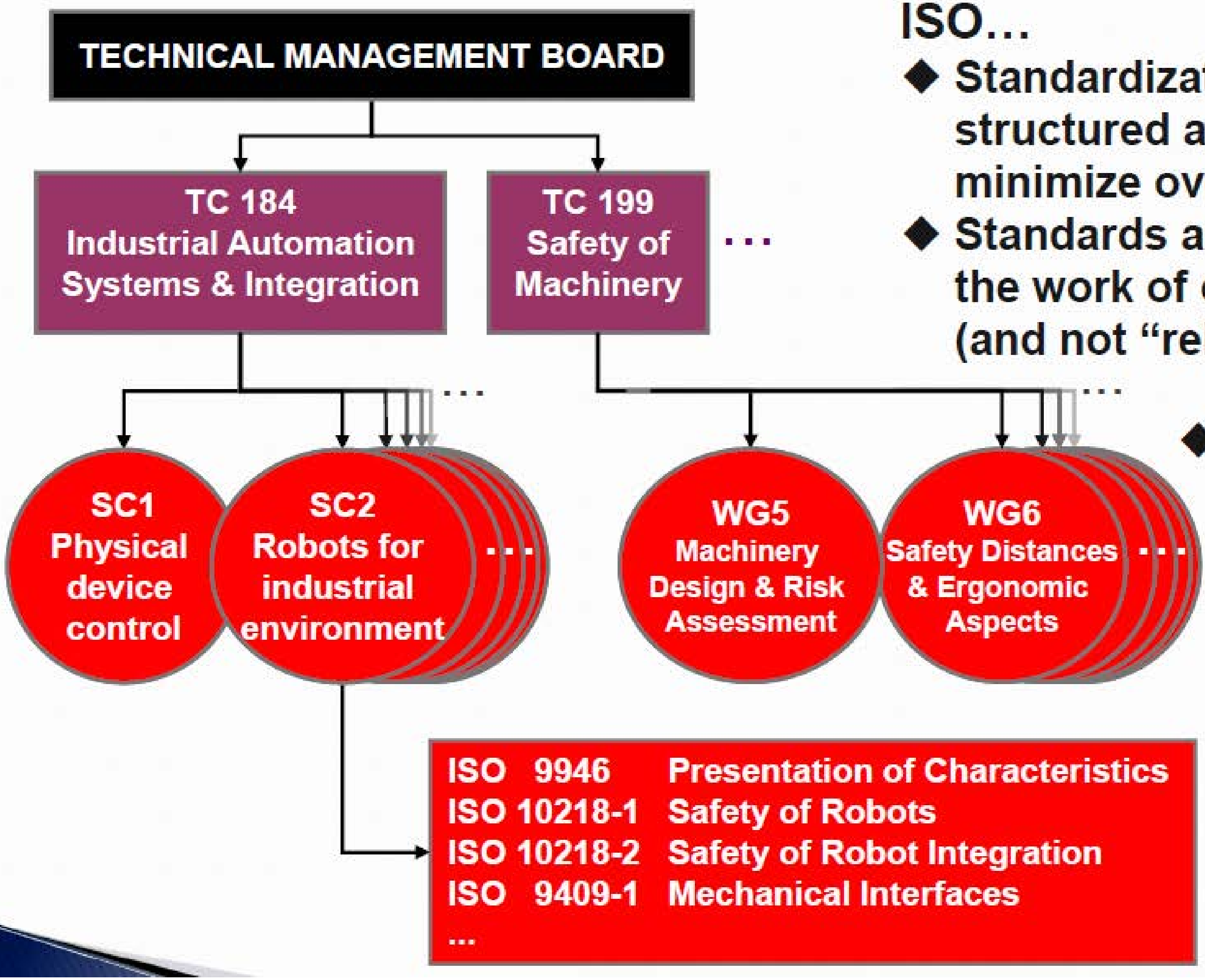
Current robot safety standards

- ISO 10218 Part 1 & Part 2 (2011)
- Technical Specification ISO/TS 15066:2016 Robots and Robotic Devices - Collaborative Robots
- ANSI/RIA R15.06 2012 American National Standard for Industrial Robots and Robot Systems- Safety Requirements
- RIA TR R15.406-2014: Safeguarding
- RIA TR R15.506-2014: Applicability of ANSI/RIA R15.06-2012 for Existing Industrial Robot Applications
- RIA TR15.606-2016 Collaborative Robots
- RIA TR15.806-2018 Guide to Testing Pressure and Force in Collaborative Robot Applications

Why are standards useful?

- Standards help level the market playing field when all players meet the standard(s).
- Standards provide risk management assistance by helping to limit liability for products meeting standard(s).
- Standards help meet market demands (presuming the market demands compliance with the standard(s)).
- Standards lower costs by standardizing designs & manufacturing.
- Globally harmonized standards allow products to be global, rather than regional designs. Equipment can be shipped between facilities of global companies.

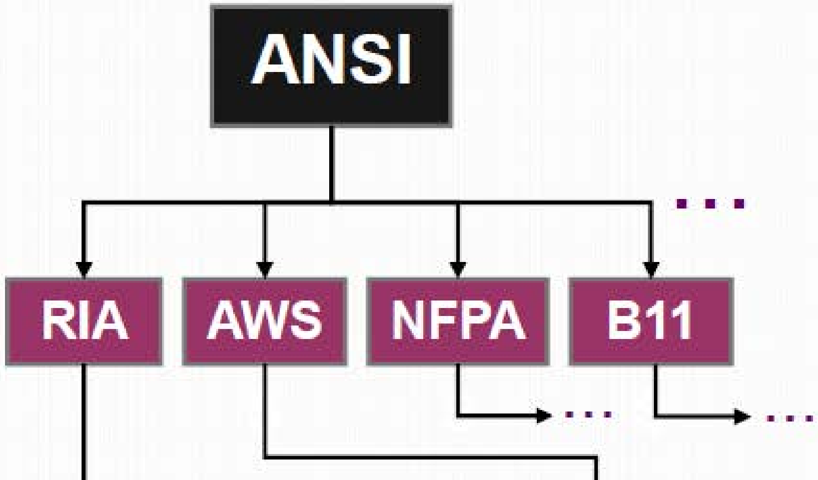
ISO standards framework



ISO…

- Standardization is highly structured and organized to minimize overlapping scopes.
- Standards are supposed to use the work of other standards (and not “reinvent the wheel”).
- For harmonized standards (EN ISO), CEN Consultants (technical experts) review the content to judge whether the standard complies with the various EU Directives.

ANSI standards framework



Over 240 standards about weld materials, techniques, certification, safety of weld robot systems, …

ANSI…

- Standards are based on market demand without oversight as to technical content.
- Accredits an organization to be a SDO (Standards Development Organization) for a specific market/ scope.
- Oversight of ANSI stds development is to its processes and the development procedures.
- Standard(s) do not have to use the work of other ANSI standards.

ANSI/ RIA R15.02	Design of Robot Control Pendants - **inactive**
ANSI/ RIA R15.05	Performance Characteristics - **inactive**
ANSI/ RIA R15.06	**Safety of Robots, + Integration of Robots, Robot Systems, Robot Cells**
ANSI/ RIA R15.07	Robot Offline Programming - **inactive**

RIA TR15.106, TR15.206, and more

Collaborative robots, definitions and terms

- Collaborative Robot
  – a robot specifically designed for direct interaction with a human within a defined collaborative workspace
- Collaborative Workspace
  - safeguarded space where the robot and a human can perform tasks simultaneously during automatic operation
- Collaborative Operation (Human-Robot Interaction)
  - state in which purpose designed robots can safety work in direct cooperation with a human within a defined workspace
- Intelligent Assist Device (IAD), also Cobot
  is a Smart lift assist device, generally not incorporating an autonomous operation mode

Benefits of human-robot collaboration

- Robots excel at simple, repetitive handling tasks.
- Humans have unique cognitive skills for understanding and adapting to any changes in the task.
- The combination of humans and robots can greatly improve performance, as long as the work is optimally shared.
- Human-robot collaboration allows for various levels of automation and human intervention. Tasks can be partially automated if a fully automated solution is not economical or too complex.
- Non-ergonomic workstations can be greatly improved with the help of robots.
- Safety of the human is an absolute prerequisite.

Robot safety features

Relevant safety features to minimize risk of a HRC application in accordance with applicable standards (ISO 10218-1:2011)

- Safe velocity monitoring
- Safe workspaces and safeguarded zones
- Safe collision detection (free collisions possible)
- Safe force monitoring (avoidance of pinching or crushing)
- Safe tool detection
- Safe switching of states (i.e. safe protection zones)

The current standard EN ISO 10218-1:2011 states that the robot is only one component in a robot system and that it is in itself insufficient for safe collaborative operation.

Means to achieve safe cobot behavior

- Safety-rated stop monitoring
- Speed and separation monitoring
- Power and force limiting
- Operation in automatic mode with a person in the collaborative workspace: When the person acts - the robot reacts.
- Incorporating specific safety design features to protect the person from injury (robot behavior = software)
- There can be both autonomous and collaborative phases in an automatic work cycle
  - Flexible adaption of the robot’s characteristics to an individual task
  - Tasks are solved through compliance, rather than programmed positions

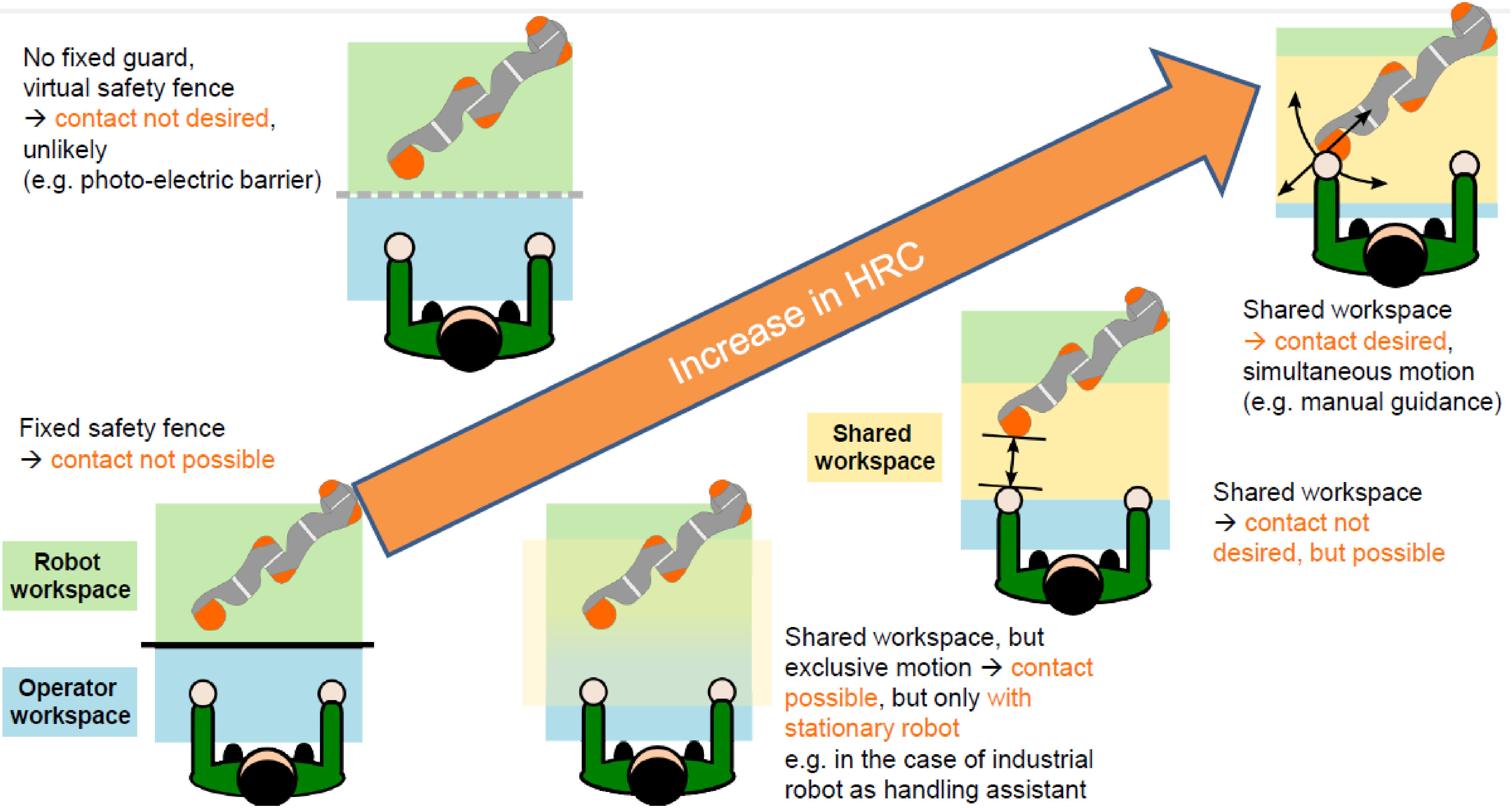
Safeguarding

- Risk Assessment should be performed at each stage of development of a robot system to determine the appropriate level of safeguarding.
- Safeguarding devices - limiting devices, sensors, fixed barriers, interlocked barrier guards.
- Awareness devices - chain or rope barriers, flashing lights, signs, whistles, horns.
- Safeguarding the teacher - restricting robot speed during programming in “teach” mode.
- Operator should be outside the robot’s restricted zone at all times.
- When a person is in a robot’s restricted envelope, the robot should be at slow speed and in “teach” mode.
- Safety training - personnel should be able to demonstrate their competence to operate robot systems safely

Other enhancement features

- Force/torque compliance – integral force/torque sensors
- Distance sensing – vision, lidar, radar sensors
- Voice interpretation - verbal command functions
- Robot artificial skin

Forms of human-robot collaboration

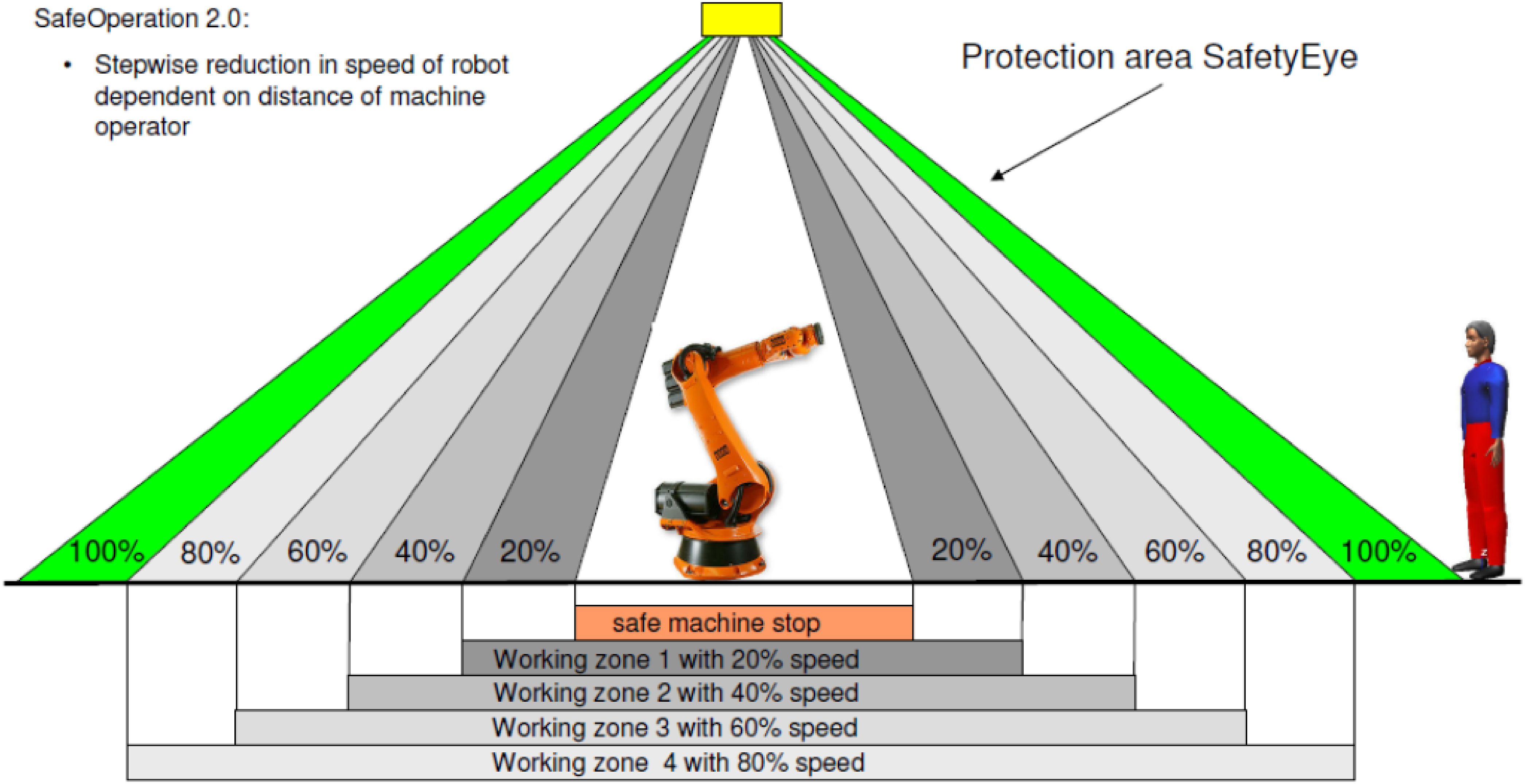


Robotic Industries Association

Safe protection zones; speed and separation

SafeOperation 2.0:

- Stepwise reduction in speed of robot dependent on distance of machine operator



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